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(71) **Applicant: DIGISONIX, LLC** [US/US]; 1801 Highway 51/138, Stoughton, WI 53589-0428 (US).

(72) **Inventor: STEENHAGEN, Shawn, K.**; 1017 North Parkview Street, Cottage Grove, WI 53527 (US).

(74) **Agents: TAKEN, Michael, E.** et al.; Andrus, Sceales, Starke & Sawall, LLP, Suite 1100, 100 East Wisconsin Avenue, Milwaukee, WI 53202 (US).

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(54) **Title:** DVE SYSTEM WITH INSTABILITY DETECTION
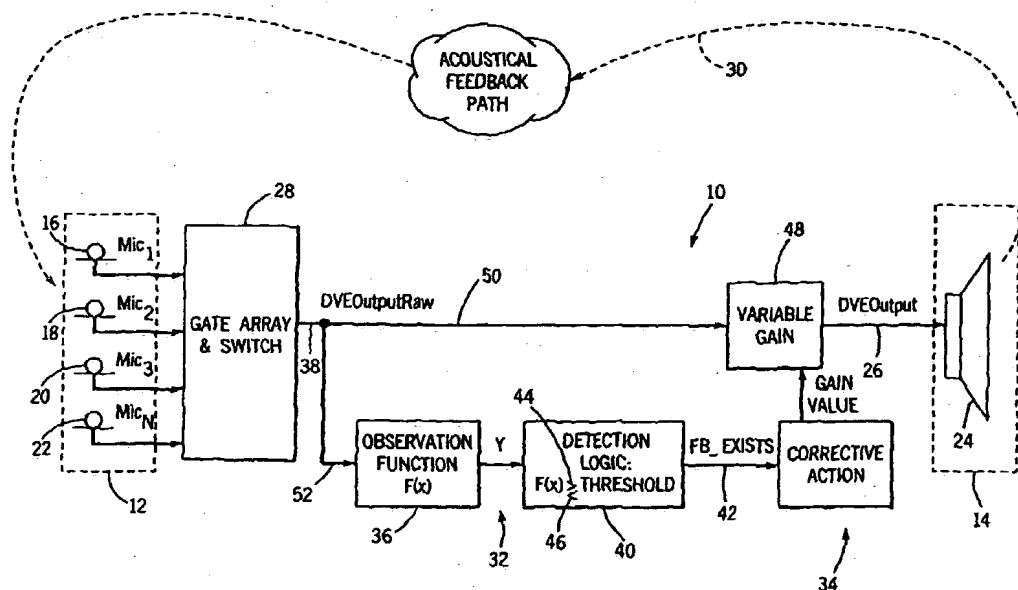
(57) **Abstract:** A digital voice enhancement, DVE, communication system (10) includes an instability detector (40) detecting an unstable acoustic feedback (30) condition from a loudspeaker (24) to a microphone (16-22) by sensing a condition of the electrical signal transmitted from the microphone (16-22) to the loudspeaker (24), and a corrective processor (34) responsive to the instability detector (40) to modify the electrical signal to reduce unstable acoustic feedback (30). The sensed electrical signal, namely the electrical signal becoming sinusoidal in nature.

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1

DVE SYSTEM WITH INSTABILITY DETECTION

BACKGROUND AND SUMMARY OF THE INVENTION

The invention relates to digital voice enhancement, DVE, communication systems, and more particularly to feedback instability detection and corrective action.

The invention may be used in duplex systems, for example as shown in U.S. Patent 5,033,082, and U.S. Application Serial No. 08/927,874, filed September 11, 1997, simplex systems, for example as shown in U.S. Application Serial No. 09/050,511, filed March 30, 1998, all incorporated herein by reference, and in other systems.

The DVE communication system includes a first acoustic zone, a second acoustic zone, a microphone at the first zone, and a loudspeaker at the second zone and electrically coupled to the microphone such that the speech of a person at the first zone can be heard by a person at the second zone as transmitted by an electrical signal from the microphone to the loudspeaker.

Under adverse conditions, instabilities can inadvertently cause feedback in DVE systems. This feedback causes the DVE controller outputs to diverge unbounded at the frequency of instability. The end result is a loud objectionable tonal squeal or screech that grows in magnitude. This is an abnormal operational state of the DVE system which must be detected and suppressed.

The present invention uses signal statistics of the electrical signal transmitted to the loudspeaker to detect a condition of instability. An instability detector detects an unstable acoustic feedback condition from the loudspeaker to the microphone by sensing a condition of the electrical signal transmitted from the microphone to the loudspeaker, and a corrective processor responds to the instability detector to modify the noted electrical signal to reduce unstable acoustic feedback.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a DVE system in accordance with the invention.

Fig. 2 illustrates a corrective method in accordance with the invention.

Fig. 3 illustrates another corrective method in accordance with the invention.

2

Fig. 4 illustrates another embodiment of a DVE system in accordance with the invention.

Fig. 5 illustrates a detection method in accordance with the invention.

Fig. 6 illustrates another detection method in accordance with the

5   invention.

Fig. 7 illustrates another detection method in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a digital voice enhancement, DVE, communication system

10   10 including a first acoustic zone 12, a second acoustic zone 14, one or more microphones 16, 18, 20, 22, etc. at the first zone, and one or more loudspeakers 24 at the second zone and electrically coupled by channel or line 26 to the microphones such that the speech of a person at a respective microphone at the first zone can be heard by a person at loudspeaker 24 at the second zone. The microphones may be in the same first

15   zone, or each microphone may be in a different first zone, or some combination thereof. Gate array and switch 28 selects which microphone to connect to loudspeaker 24, and is preferably provided by a short-time average magnitude estimating function to detect if a voice signal is present from the respective microphone, though other estimating functions may be used, for example Digital Processing of Speech Signals, Lawrence W.

20   Rabiner, Ronald W. Schafer, 1978, Bell Laboratories, Inc., Prentice-Hall, pages 120-126, and also as noted in U.S. Patent 5,706,344, incorporated herein by reference. Loudspeaker 24 is acoustically coupled to the microphones as shown at feedback path 30 such that the microphones are subject to acoustic feedback from loudspeaker 24. An instability detector 32 detects an unstable acoustic feedback condition from loudspeaker

25   24 to microphone 16 by sensing a condition of the electrical signal transmitted from microphone 16 to loudspeaker 24, and likewise for the remaining microphones. A corrective processor 34 responds to the instability detector to modify the electrical signal transmitted to loudspeaker 24 to reduce unstable acoustic feedback. Instability detector 32 and corrective processor 34 prevent divergence and unbounded growth of the

30   magnitude of the electrical signal at 26 otherwise caused at frequencies of instability in the noted unstable acoustic feedback condition. The noted sensed condition of the

electrical signal may be magnitude of the electrical signal greater than a designated

threshold, power (magnitude^2) of the electrical signal greater than a designated

threshold, or, preferably, the sinusoidal characteristic of the electrical signal, i.e. the

electrical signal becoming sinusoidal in nature, to be described.

5   In the noted preferred embodiment, instability detector 32 is provided by a

model 36 modeling the noted electrical signal from output 38 of the gate array and

switch 28 as a filter model with filter coefficients, for example as in U.S. Patents

4,677,676, 4,677,677, 4,987,598, 5,033,082, 5,172,416, 5,206,911, 5,386,477,

5,396,561, 5,621,803, 5,680,337, 5,706,344, 5,710,822, 5,715,320, all incorporated

10   herein by reference. An unstable feedback condition in the DVE system is detected by

determining that the DVE output at 38 has become sinusoidal, or tonal, in nature. The

tonal condition is identified by continually modeling the DVE output at 38 as a second

order all pole filter and monitoring one of the filter coefficients. Under normal voice

output conditions, the variation of such filter coefficient is large. At the onset of

15   feedback, the DVE output at 38 becomes sinusoidal, and the variation of the filter

coefficient becomes very small. Instability detector 32 includes detection logic 40

monitoring the filter coefficient and outputting a feedback indicator signal at 42 to

corrective processor 34 in response to a given condition of the filter coefficient. In

contrast to the above noted method of outputting feedback indicator signal 42 when the

20   magnitude or power of the electrical signal is greater than a designated threshold as

shown at greater-than sign 44, the tonal sinusoid sensing of the preferred detection

method outputs feedback indicator signal 42 when the variation of the noted filter

coefficient is below a designated threshold as shown at less-than sign 46. Model 36 is

preferably a second order all pole filter model, as noted above. Detection logic 40

25   outputs feedback indicator signal 42 to corrective processor 34 when the variation of the

filter coefficient is below a designated threshold. Corrective processor 34 includes a

variable gain element 48 applying variable gain to the electrical signal after sensing by

instability detector 32. The corrective processor responds to the noted sensed condition

of the electrical signal to vary the gain applied at 48. The electrical signal at 38 is

30   supplied to parallel branches 50 and 52. Branch 50 is supplied to variable gain element

48 and loudspeaker 24. Branch 52 is supplied to instability detector 32 and corrective processor 34.

In one embodiment, corrective processor 34 responds to the noted sensed condition from instability detector 32 by reducing gain, Fig. 2, e.g. setting the DVE

5   variable gain at element 48 to zero, then instituting a delay, e.g. wait 1 to 5 seconds, then resetting the gate array and switch 28 to an initialized condition such that the latter may again sense the active microphone, and then increasing the gain, e.g. setting the DVE variable gain to 1 or back to its value prior to the reducing of the gain. In another embodiment, Fig. 3, the gain is reduced, e.g. by half, and then a delay is instituted, e.g.

10   0.5 seconds, and then the gate array and switch is reset, and then monitoring of the instability detector is resumed.

In preferred form, instability detector 36 uses Prony's method of sinusoidal identification as described in <u>Handbook For Digital Signal Processing</u>, Sanjit K. Mitra and James F. Kaiser, 1993, John Wiley & Sons, pages 1193-1195. This method is used

15   to identify the sinusoidal components of an input signal. Fig. 4 shows implementation and uses like reference numerals from above where appropriate to facilitate understanding. Gate array and switch 28 is broken out into its respective gates 54, 56, 58, 60, etc., one for each microphone, and DVE switch component 62. The detector uses the Prony method for a number of poles equal to 2 to match the electrical signal to

20   a single sinusoid, which requires a data sample size of only 4, which small size is considered desirable.

Prony's method with p=2, N=4 gives the **a** coefficients of an all pole model:

a=[1 a1 a2]

25   where

$$x(n) \equiv [x(k\text{-}3) \ x(k\text{-}2) \ x(k\text{-}1) \ x(k)] \equiv [x(0) \ x(1) \ x(2) \ x(3)]$$

$$a2 = \frac{-x(3) \cdot x(1) + x(2)^2}{x(1)^2 - x(0) \cdot x(2)}$$

$$a1 = \frac{-x(2) - a2 \cdot x(0)}{x(1)}$$

The roots of a tell the pole locations, and the angle of the pole is the frequency of the sinusoid.

The DVE output is continually modeled using Prony's method, looking for a trend in the results that indicate a tone is present. The "results" to be monitored can be the a1 & a2 coefficients, the location of the poles, the amplitude of the poles, etc., all of which will stabilize when the signal is sinusoidal. In the preferred embodiment, only the a2 coefficient need be calculated. The present detection method is based on the fact that under feedback conditions when the DVE output 38 is sinusoidal, the a2 coefficient becomes very stable compared to all other normal operating conditions, i.e. under normal operating conditions the a2 coefficient is random. This method of feedback detection offers the following advantages over other detection methods: a) such method creates a single parameter whose value answers the question as to whether the output is sinusoidal; b) such method differentiates between abnormal sinusoidal signals and normal voice signals; c) such method is not prone to false detections that occur in output power monitoring methods under conditions of wind noise, door slams and microphone thumps; and d) such method requires a buffer size of only four data samples, as compared to buffer sizes of 512 or more data samples required by fast Fourier transform techniques or correlation based statistical methods.

In one form, the detection method compares the a2 coefficient to 1.0, Fig. 5. In a pure tone, the second order all pole model is of the form

$$a(z) = 1 + 2\cos\theta \cdot z^{-1} + z^{-2} \quad \text{or} \quad [a0\ a1\ a2] = [1\ 2\cos\theta\ 1]$$

Therefore, when the signal is tonal in nature, a2 will equal 1. The detection method observes the average magnitude of the difference of a2 and 1.0. The average magnitude is obtained using a typical averaging equation:

$$\text{avg\_mag}(k+1) = \text{avg\_mag}(k) + 1/(\text{tau}*\text{fs})*(\text{abs}(\text{input}(k)) - \text{avg\_mag}(k))$$

wherein input(k) = a2(k)-1.0 and a2(k) is calculated from Prony's equation shown above.

In another form, Fig. 6, the method uses the fact that under sinusoidal conditions the a2 coefficient is very stable, i.e. its difference about its mean value is small. This characteristic is used to detect tonal or periodic signals by measuring the average magnitude of a2(k)-a2(k-1). The gate truth and gate energy signals indicate

6

whether there is voice activity and the amount of power on the respective microphone, respectively, and the active mic gate truth and active mic gate energy signals provide the noted signals for comparison for the active microphone. The gate information could be used to only enable the detection logic when there is signal or voice activity from the

5   microphone and/or when signal power or energy from the microphone is above a given level, i.e. the detection logic is enabled to output the feedback indicator signal to the corrective processor only by an activity signal from the microphone, i.e. active mic or gate truth signal, and/or signal energy or power from the microphone above a given level, i.e. active mic gate energy. This will avoid detection "falses" when the input

10   signal is zero or near zero.

Fig. 7 shows a modification of the above method of Fig. 6 and is more robust. Fig. 7 measures the variance of the a2 coefficient. The variance of a signal is defined as the $E\{X^2\}-(E\{X\})^2$. For zero mean signals, $(E\{X\}=0)$, the variance is simply $E\{X^2\}$, which is the average power. Since $X=a2(k)-a2(k-1)$ is a simple high pass filter,

15   mean(X)=0, and its variance can be monitored by monitoring its average power $E\{X^2\}$. The average power of the difference is monitored using a typical averaging scheme:

$$avg\_pwr(k+1) = avg\_pwr(k) + 1/(tau*fs)*(input(k)^2 - avg\_pwr(k))$$

wherein input(k) = a2(k)-a2(k-1) and a2(k) is calculated from Prony's equation shown above.

20   It is recognized that various equivalents, alternatives and modifications are possible within the scope of the appended claims.

7

CLAIMS

What is claimed is:

1. A digital voice enhancement communication system comprising:

a first acoustic zone;

a second acoustic zone;

a microphone at said first zone;

5   a loudspeaker at said second zone and electrically coupled to said microphone such that the speech of a person at said first zone can be heard by a person at said second zone as transmitted by an electrical signal from said microphone to said loudspeaker, said loudspeaker being acoustically coupled to said microphone such that said microphone is subject to acoustic feedback from said loudspeaker;

10   an instability detector detecting an unstable acoustic feedback condition from said loudspeaker to said microphone by sensing a condition of said electrical signal transmitted from said microphone to said loudspeaker;

a corrective processor responsive to said instability detector to modify said electrical signal to reduce unstable acoustic feedback.

2. The invention according to claim 1 wherein said instability detector and said corrective processor prevent divergence and unbounded growth of the magnitude of said electrical signal otherwise caused at frequencies of instability in said unstable acoustic feedback condition.

3. The invention according to claim 1 wherein said sensed condition is magnitude of said electrical signal greater than a designated threshold.

4. The invention according to claim 1 wherein said sensed condition is power of said electrical signal greater than a designated threshold.

5. The invention according to claim 1 wherein said sensed condition is a sinusoidal characteristic of said electrical signal.

6. The invention according to claim 5 wherein said sensed condition is said electrical signal becoming sinusoidal in nature.

7. The invention according to claim 6 wherein said instability detector comprises:

8

a model modeling said electrical signal as a filter model with filter coefficients;

detection logic monitoring one of said filter coefficients and outputting a feedback indicator signal to said corrective processor in response to a given condition of said filter coefficient.

8. The invention according to claim 7 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the variation of said filter coefficient is below a designated threshold.

9. The invention according to claim 8 wherein said model is an all pole filter model.

10. The invention according to claim 9 wherein said model is a second order all pole filter model.

11. The invention according to claim 7 wherein said instability detector identifies said filter coefficient with as few as four data samples.

12. The invention according to claim 11 wherein said instability detector identifies said filter coefficient with only four data samples.

13. The invention according to claim 8 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the magnitude of the variation of said filter coefficient is below said designated threshold.

14. The invention according to claim 13 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the average magnitude of the variation of said filter coefficient is below said designated threshold.

15. The invention according to claim 8 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the power of the variation of said filter coefficient is below said designated threshold.

16. The invention according to claim 15 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the average power of the variation of said filter coefficient is below said designated threshold.

17. The invention according to claim 7 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the magnitude

of the difference between said filter coefficient and a given value is below a designated threshold.

18. The invention according to claim 17 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the average magnitude of the difference between said filter coefficient and a given value is below a designated threshold.

19. The invention according to claim 17 wherein said given value is 1.0.

20. The invention according to claim 7 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the power of the difference between said filter coefficient and a given value is below a designated threshold.

21. The invention according to claim 20 wherein said detection logic outputs said feedback indicator signal to said corrective processor when the average power of the difference between said filter coefficient and a given value is below a designated threshold.

22. The invention according to claim 20 wherein said given value is 1.0.

23. The invention according to claim 1 wherein said corrective processor comprises a variable gain element applying variable gain to said electrical signal after said sensing by said instability detector.

24. The invention according to claim 23 wherein said corrective processor responds to said sensed condition of said electrical signal to vary said gain.

25. The invention according to claim 24 wherein said electrical signal is supplied to first and second parallel branches, said first branch being supplied to said variable gain element and said loudspeaker, said second branch being supplied to said instability detector and said corrective processor.

26. The invention according to claim 24 comprising a plurality of microphones, a gate array and switch for selecting which microphone to connect to said loudspeaker, said gate array and switch having a plurality of inputs, one from each microphone, and an output supplied to parallel first and second branches, said first
5   branch being supplied to said variable gain element and said loudspeaker, said second branch being supplied to said instability detector and said corrective processor.

27. The invention according to claim 26 wherein said corrective processor responds to said sensed condition from said instability detector by reducing said gain, then instituting a delay, then resetting said gate array and switch.

28. The invention according to claim 26 wherein said corrective processor responds to said sensed condition from said instability detector by reducing said gain, then instituting a delay, then resetting said gate array and switch, then increasing said gain.

29. The invention according to claim 28 wherein said increasing of said gain increases said gain back to its value prior to said reducing of said gain.

30. The invention according to claim 28 wherein said reducing of said gain reduces said gain to zero.

31. The invention according to claim 26 wherein said corrective processor responds to said sensed condition from said instability detector by reducing said gain, then instituting a delay, then resetting said gate array and switch, then resuming monitoring of said instability detector.

32. The invention according to claim 7 wherein said detection logic outputs said feedback indicator signal to said corrective processor in response to a given condition of said filter coefficient in combination with a given condition of said microphone.

33. The invention according to claim 32 wherein said given condition of said microphone is whether there is signal activity from said microphone.

34. The invention according to claim 32 wherein said given condition of said microphone is the signal level energy from said microphone.

35. The invention according to claim 32 wherein said given condition of said microphone is both whether there is signal activity from said microphone and the signal level energy from said microphone.

36. The invention according to claim 32 wherein said detection logic is enabled to output said feedback indicator signal to said corrective processor only by at least one of a) a signal activity signal from said microphone and b) signal energy from said microphone above a given level.

11

37. A digital voice enhancement communication system comprising:

a first acoustic zone;

a second acoustic zone;

a microphone at said first zone;

5   a loudspeaker at said second zone and electrically coupled to said microphone such that the speech of a person at said first zone can be heard by a person at said second zone as transmitted by an electrical signal from said microphone to said loudspeaker, said loudspeaker being acoustically coupled to said microphone such that said microphone is subject to acoustic feedback from said loudspeaker;

10   a Prony signal identifier detecting a sinusoidal tonal condition of said electrical signal transmitted from said microphone to said loudspeaker as an indication of unstable acoustical feedback from said loudspeaker to said microphone;

a corrective processor responsive to said Prony signal identifier to modify said electrical signal to reduce unstable acoustic feedback.

38. A method for detecting and reducing instability in a digital voice enhancement communication system having a first acoustic zone, a second acoustic zone, a microphone at said first zone, a loudspeaker at said second zone and electrically coupled to said microphone such that the speech of a person at said first zone can be

5   heard by a person at said second zone as transmitted by an electrical signal from said microphone to said loudspeaker, said loudspeaker being acoustically coupled to said microphone such that said microphone is subject to acoustic feedback from said loudspeaker, said method comprising detecting an unstable acoustic feedback condition from said loudspeaker to said microphone by sensing a condition of said electrical signal

10   transmitted from said microphone to said loudspeaker, and responding to said sensed condition to modify said electrical signal to reduce unstable acoustic feedback.

39. The method according to claim 38 comprising using said detection and modification to prevent divergence and unbounded growth of the magnitude of said electrical signal otherwise caused at frequencies of instability in said unstable acoustic feedback condition.

40. The method according to claim 38 wherein said sensed condition is magnitude of said electrical signal greater than a designated threshold.

11

12

41. The method according to claim 38 wherein said sensed condition is power of said electrical signal greater than a designated threshold.

42. The method according to claim 38 wherein said sensed condition is a sinusoidal characteristic of said electrical signal.

43. The method according to claim 42 wherein said sensed condition is said electrical signal becoming sinusoidal in nature.

44. The method according to claim 43 comprising modeling said electrical signal as a filter model with filter coefficients, and monitoring one of said filter coefficients and generating a feedback indicator signal to modify said electrical signal in response to a given condition of said filter coefficient.

45. The method according to claim 44 comprising generating said feedback indicator signal when the variation of said filter coefficient is below a designated threshold.

46. The method according to claim 45 comprising modeling said electrical signal as an all pole filter model.

47. The method according to claim 46 comprising modeling said electrical signal as a second order all pole filter model.

48. The method according to claim 44 comprising identifying said filter coefficient with as few as four data samples.

49. The method according to claim 48 comprising identifying said filter coefficient with only four data samples.

50. The method according to claim 45 comprising generating said feedback indicator signal when the magnitude of the variation of said filter coefficient is below said designated threshold.

51. The method according to claim 50 comprising generating said feedback indicator signal when the average magnitude of the variation of said filter coefficient is below said designated threshold.

52. The method according to claim 45 comprising generating said feedback indicator signal when the power of the variation of said filter coefficient is below said designated threshold.

53. The method according to claim 52 comprising generating said feedback indicator signal when the average power of the variation of said filter coefficient is below said designated threshold.

54. The method according to claim 33 comprising generating said feedback indicator signal when the magnitude of the difference between said filter coefficient and a given value is below a designated threshold.

55. The method according to claim 54 comprising generating said feedback indicator signal when the average magnitude of the difference between said filter coefficient and a given value is below a designated threshold.

56. The method according to claim 54 wherein said given value is 1.0.

57. The method according to claim 33 comprising generating said feedback indicator signal when the power of the difference between said filter coefficient and a given value is below a designated threshold.

58. The method according to claim 57 comprising generating said feedback indicator signal when the average power of the difference between said filter coefficient and a given value is below a designated threshold.

59. The method according to claim 58 wherein said given value is 1.0.

60. The method according to claim 38 comprising applying variable gain to said electrical signal after said sensing.

61. The method according to claim 60 comprising modifying said electrical signal by varying said gain in response to said sensed condition.

62. The method according to claim 61 comprising supplying said electrical signal to parallel first and second branches, applying said variable gain to said electrical signal on said first branch, and detecting said unstable acoustic feedback condition from said loudspeaker to said microphone by sensing said condition of said electrical signal on said second branch and responding thereto to modify said electrical signal on said first branch by varying said gain.

63. The method according to claim 61 wherein said digital voice enhancement communication system has a plurality of microphones each having a gate, and a switch for selecting which microphone to connect to said loudspeaker, said switch having a plurality of inputs, one from each gate, and an output transmitting said

14

5   electrical signal, and comprising supplying said electrical signal from said output to

parallel first and second branches, applying said variable gain to said electrical signal on

said first branch, and detecting said unstable acoustic feedback condition from said

loudspeaker to said microphone by sensing said condition of said electrical signal on

said second branch and responding thereto to modify said electrical signal on said first

10   branch by varying said gain.

64. The method according to claim 63 comprising responding to said

sensed condition by generating said feedback indicator signal to reduce said gain, then

instituting a delay, then resetting said gates and said switch.

65. The method according to claim 63 comprising responding to said

sensed condition by generating said feedback indicator signal to reduce said gain, then

instituting a delay, then resetting said gates and said switch, then increasing said gain.

66. The method according to claim 65 comprising increasing said gain by

increasing gain back to its value prior to said reducing of said gain.

67. The method according to claim 65 comprising reducing said gain by

reducing gain to zero.

68. The method according to claim 63 comprising responding to said

sensed condition by generating said feedback indicator signal to reduce said gain, then

instituting a delay, then resetting said gates and said switch, then resuming monitoring

of said sensed condition.

69. The method according to claim 33 comprising generating said

feedback indicator signal in response to a given condition of said filter coefficient in

combination with a given condition of said microphone.

70. The method according to claim 69 wherein said given condition of

said microphone is whether there is signal activity from said microphone.

71. The method according to claim 69 wherein said given condition of

said microphone is the signal level energy from said microphone.

72. The method according to claim 69 wherein said given condition of

said microphone is both whether there is signal activity from said microphone and the

signal level energy from said microphone.

14

73. The method according to claim 69 comprising enabling said detection logic to output said feedback indicator signal to said corrective processor responsive to said given condition of said filter coefficient only additionally in response to at least one of a) a signal activity signal from said microphone and b) signal energy from said microphone above a given level.

74. A method for detecting and reducing instability in a digital voice enhancement communication system having a first acoustic zone, a second acoustic zone, a microphone at said first zone, a loudspeaker at said second zone and electrically coupled to said microphone such that the speech of a person at said first zone can be heard by a person at said second zone as transmitted by an electrical signal from said microphone to said loudspeaker, said loudspeaker being acoustically coupled to said microphone such that said loudspeaker is subject to acoustic feedback from said loudspeaker, said method comprising detecting an unstable acoustic feedback condition from said loudspeaker to said microphone by Prony identification of a sinusoidal tonal condition of said electrical signal transmitted from said microphone to said loudspeaker and responding thereto to generate a feedback indicator signal to modify said electrical signal to reduce unstable acoustic feedback.

FIG. 1
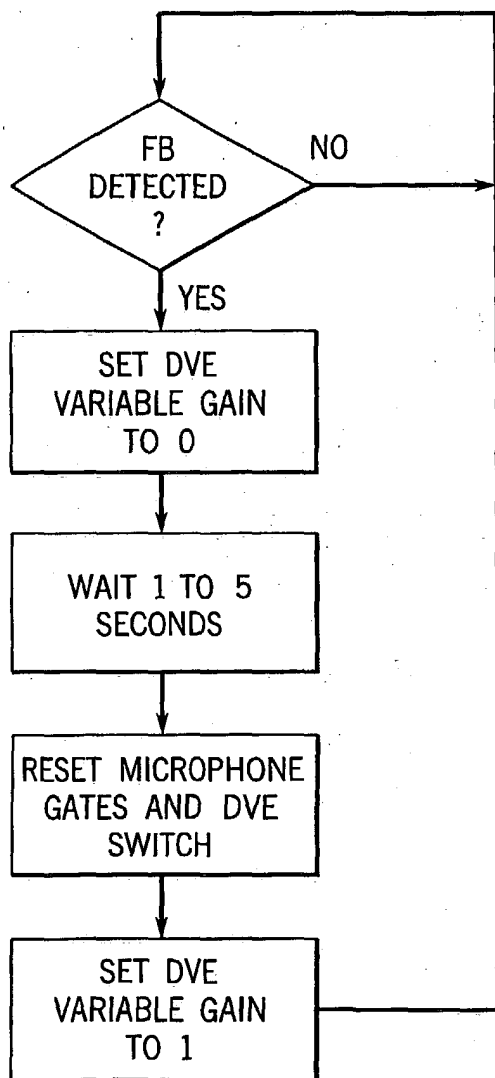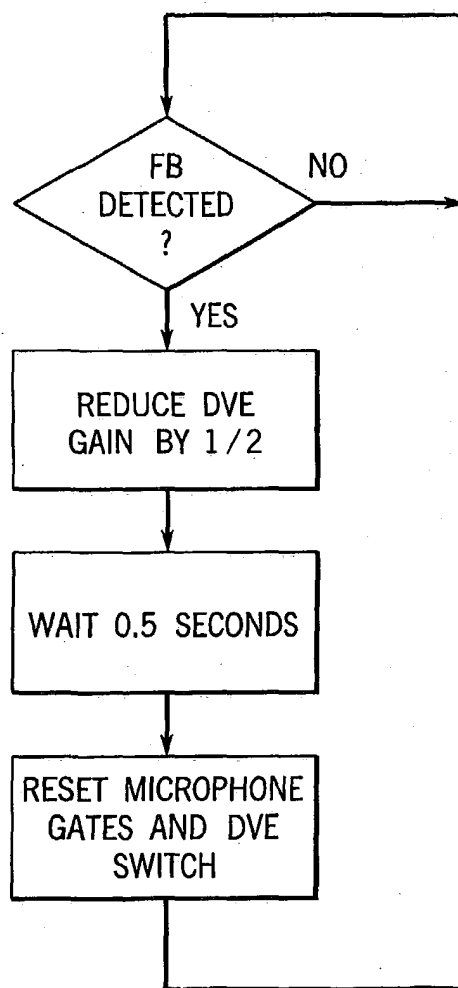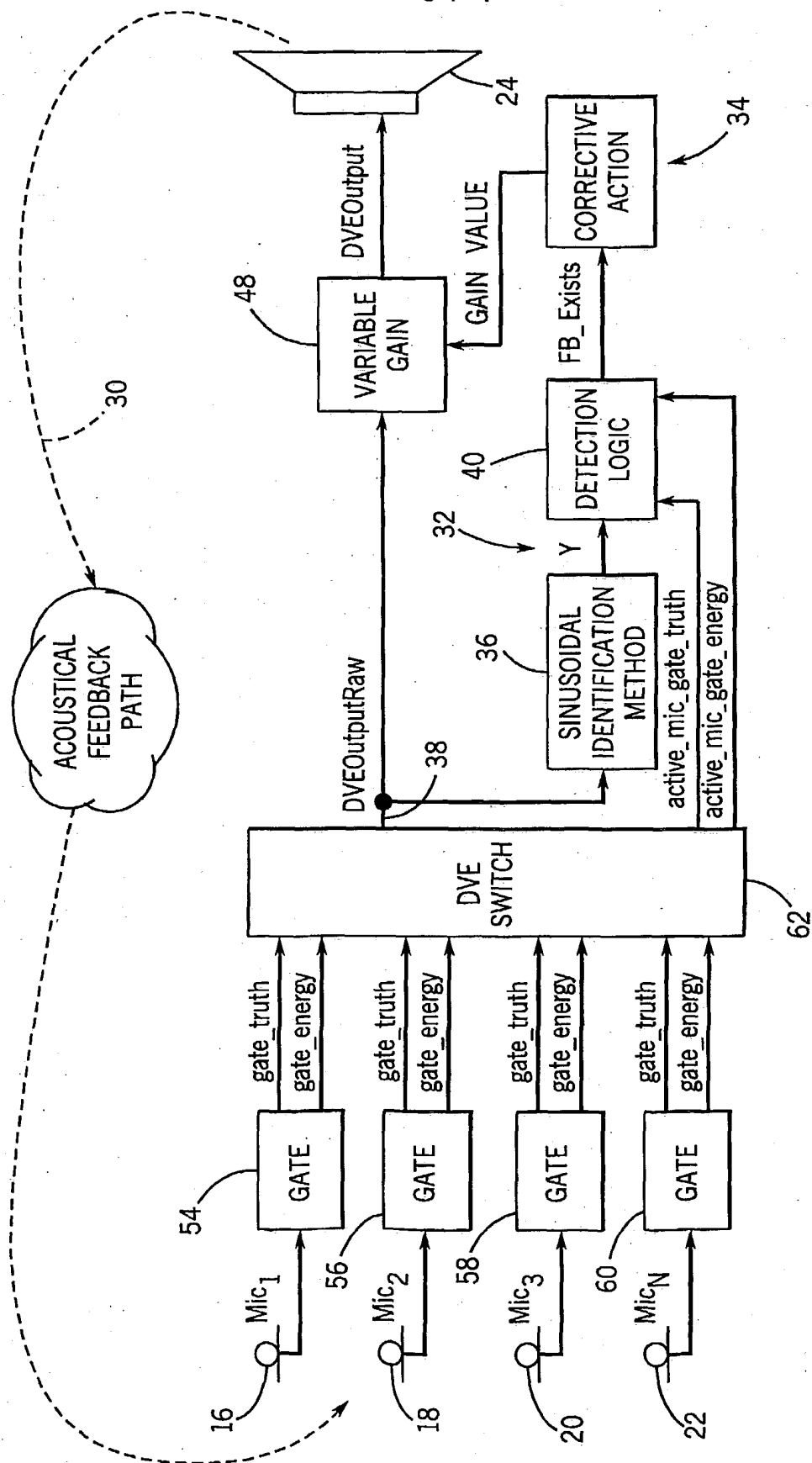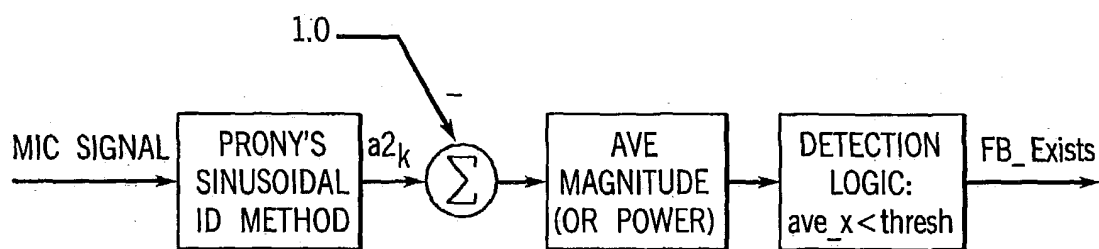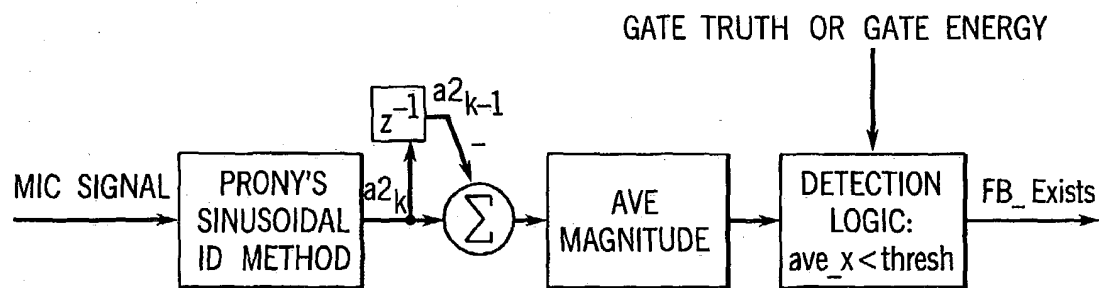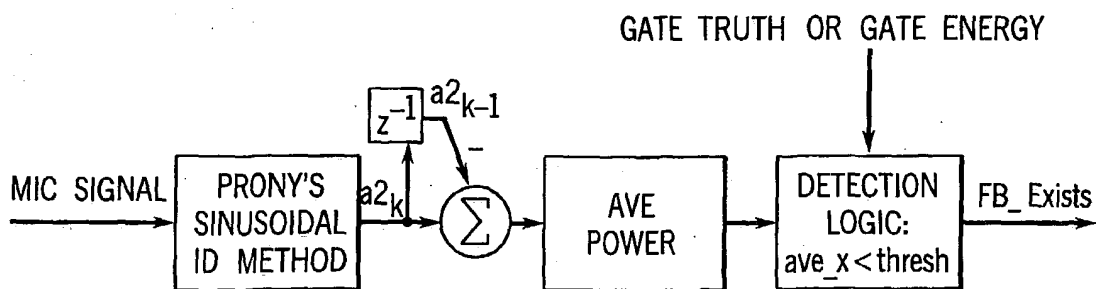
FIG. 2

FIG. 3

FIG. 4

MIC SIGNAL → PRONY'S SINUSOIDAL ID METHOD → $a2_k$ → Σ (with 1.0 input, −) → AVE MAGNITUDE (OR POWER) → DETECTION LOGIC: ave_x < thresh → FB_Exists

FIG. 5

MIC SIGNAL → PRONY'S SINUSOIDAL ID METHOD → $a2_k$ → z^{-1} → $a2_{k-1}$ → Σ (−) → AVE MAGNITUDE → DETECTION LOGIC: ave_x < thresh → FB_Exists

GATE TRUTH OR GATE ENERGY ↓

FIG. 6

MIC SIGNAL → PRONY'S SINUSOIDAL ID METHOD → $a2_k$ → z^{-1} → $a2_{k-1}$ → Σ (−) → AVE POWER → DETECTION LOGIC: ave_x < thresh → FB_Exists

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FIG. 7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7)   :   H03G 3/20; HO4R 27/00; H04B 15/00; A61F 11/06
US CL   :   381/110, 83, 93, 71.1, 94.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
    U.S. : 381/110, 83, 93, 71.1, 94.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Mitra, S. K. and Kaiser, James F., Handbook for Digital Signal Processing. 1993, John Wiley & Sons, pages 1193-1195.	37 and 74
X, P	US 6,295,364 B1 (FINN et al) 25 September 2001 (25.09.2001), col. 1, lines 38-42 and col. 2, lines 16-55 and figure 1 and col. 3, lines 64-67 and col. 4, lines 1-64.	1 and 38
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Y, P		37 and 74
X	US 5,677,987 A (SEKI et al) 14 October 1997 (14.10.1997), col. 6, lines 28-63 and figure 2.	1-3, 5-6, 38-40 and 42-43
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Y		37 and 74
Y	US 5,377,277 A (BISPING) 27 December 1994 (27.12.1994), col. 6, lines 65-68 and col. 7, lines 1-68 and col. 8, lines 1-32.	37 and 74

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier application or patent published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 April 2002 (24.04.2002)	10 JUN 2002

Name and mailing address of the ISA/US
    Commissioner of Patents and Trademarks
    Box PCT
    Washington, D.C. 20231
Facsimile No. (703)305-3230
	Authorized officer
	    Forester W. Isen
	Telephone No. (703) 305-4700

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